

NANTICOKE
SPRING GRAIN STUDY
- 1985

ARB-169-86- Phyto

JULY 1987



Ontario

Ministry
of the
Environment

E. PICHÉ, Director
Air Resources Branch

NANTICOKE SPRING GRAIN STUDY - 1985

Authors: R.G. Pearson

B. Archibald

H. Bentley

Report No. ARB-169-86-Phyto

JULY 1987

TABLE OF CONTENTS

NANTICOKE SPRING GRAIN STUDY - 1985

	PAGE
A. EXECUTIVE SUMMARY	1
B. BACKGROUND INFORMATION	2
C. STUDY OUTLINE	5
D. REVIEW OF SO ₂ - PLANT RESPONSE LITERATURE	6
E. SO ₂ MONITORING RESULTS - NANTICOKE AREA	8
F. COMPARISON OF AIR MONITORING RESULTS WITH DOSE - RESPONSE AND HISTORICAL BARLEY YIELDS	10
G. FIELD INVESTIGATION ITINERARY (MOE AND OMAF)	12
H. DISCUSSION OF RESULTS	13
H.1 MOE Findings	13
H.1.1 Soil Analyses Results	13
H.1.2 Foliar Analyses Results	15
H.1.3 Soil and Crop Physical Characteristics	16
H.1.4 Visual Observations	17
H.2 OMAF Findings	17
H.2.1 Agronomic Questionnaire	17
H.2.2 Soil Fertility Analyses	18
H.2.3 Barley Tissue Test Analyses	18
H.2.4 Barley Yield Results	19
H.2.5 Evaluation of Rainfall Data	19
H.2.6 Visual Observations	20
I. CONCLUSIONS	20
J. REFERENCES CITED	21

LIST OF TABLES

<u>Table No.</u>	<u>Title</u>	<u>Page No.</u>
1	Summary of Literature Survey Citings for SO ₂ Effects on Cereals	23
2	Dose Response Relationship from Literature Review for SO ₂ Concentration and Duration Resulting in Threshold or Minimal Foliar Injury and Yield/Growth Effects in Cereals	7
3	Summary of Air Quality Monitoring Results (SO ₂) for the Nanticoke Spring Study Area: 1975-1985	27
4	Comparison of Air Quality Monitoring Results (SO ₂) for the Nanticoke Spring Grain Study Area on a Monthly Basis	28
5	Comparison of Dose-Response Information for Cereals with Actual Monitoring Results in the Nanticoke Spring Grain Study Area: 1975-1985	11
6	Historical Comparison of Barley Yield 1975-1985	29
7	Relationship Between Average Growing Season (April-August) SO ₂ Air Quality Levels and Historical Barley Yields in the Nanticoke Spring Grain Study Area: 1975-1985	30
8	Summary of Soil Analyses Results for Samples Collected in the Nanticoke Spring Grain Study Area - May 30, 31 and June 3, 1985	31
9	Comparison of Barley Field and Corresponding Fence Row Soil Analyses Results for Sampling Sites in the Nanticoke Spring Grain Study Area - 1985	32
10	Statistical Evaluation Results For All Soil and Barley Foliage Chemical and Physical Parameters - 1985	33

LIST OF TABLES (cont'd)

<u>Table No.</u>	<u>Title</u>	<u>Page No.</u>
11	Relationship Between Soil Chemical and Fertility Parameters and Barley Yield at All Nanticoke Spring Grain Study Sites - 1985	34
12	Summary of Barley Analyses Results for Samples Collected in the Nanticoke Spring Study Area - July 10-11, 1985	35
13	Relationship Between Barley Foliar Chemistry and Crop Yield at All Nanticoke Spring Grain Study Sites - 1985	36
14	Comparison of Soil Physical Properties at All Nanticoke Spring Grain Study Sites - 1985	37
15	Summary of Barley Physical Characteristics and Hand Harvested Barley Yield for All Sites in the Nanticoke Spring Grain Study Area - 1985	38
16	Relationship Between Crop and Soil Physical Parameters and Barley Yield at All Nanticoke Spring Grain Study Sites - 1985	39
17	Description of Barley Study Sites - Field History	40
18	Description of Barley Study Sites - Tillage Operations	41
19	Description of Barley Study sites - Planting and Herbicide Data	42
20	Summary of OMAF - Soil Test Results - 1985	43
21	Summary of OMAF - Plant Tissue Analyses Results - 1985	44
22	Haldimand Co. Rainfall Records (1975-1985)	45

LIST OF FIGURES

<u>Figure No.</u>	<u>Title</u>	<u>Page No.</u>
1	Dose Response Curve for Threshold/Minimal Foliar Injury Based on Literature Citings	46
2	Dose Response Curve for Threshold/Minimal Yield or Growth Effects Based on Literature Citings	47
3	Location of Air Monitors in the Nanticoke Area - 1975-85	48
4	Location of Barley Study Sites in the Nanticoke Area - 1985	49
5	Regression of Historical Barley Yield on Rainfall During April-June: 1975-85	50

NANTICOKE SPRING GRAIN

STUDY - 1985

A. EXECUTIVE SUMMARY

In 1985, following numerous complaints from farmers in the vicinity of the Nanticoke industrial complex that they could no longer grow spring cereal crops due to adverse air quality conditions a joint Ministry of Agriculture and Food - Ministry of Environment study was initiated.

The study consisted of establishing a total of 15 spring barley study sites throughout the area to the N and NE of the industrial complex and in a control area located well remote from the area of concern but with similar soil and meteorological conditions.

During the growing season the sites were observed and sampled extensively for foliar chemistry, nutrient status, soil accumulation and fertility parameters. The physical condition of the various soils and barley crops also was recorded and all sites were harvested for yield determination.

In all, over 3000 chemical and physical test parameters were generated for evaluation.

In addition to the crop monitoring in 1985, historical barley yields from this area were obtained from the Crop Insurance Commission and compared with rainfall data and with SO₂ air quality monitoring results during the past 11 years. The SO₂ data alone represent almost 500,000 hours of continuous monitoring in this area. These seasonal air quality parameters were then compared with the dose-response relationships that were obtained from a thorough review of the scientific literature.

The results of this investigation failed to find any relationship between historical air quality (sulphur dioxide) patterns and crop productivity. The 1985 results also ruled out any significant elemental deposition or foliar contamination which would be detrimental to the growth of spring grains in this area.

The findings did however, reveal that the heavy clay soils in this area are prone to severe hard-pan formation and to adverse weather (rainfall) conditions. In this regard, spring planting date appears to be the single greatest factor affecting crop yield, with wet springs resulting in late planting and reduced yields.

B. BACKGROUND INFORMATION

In late 1984 and early 1985 complaints concerning the growth of spring grains in the vicinity of the Nanticoke industrial complex were received by the West Central Region of the Ministry of Environment (MOE) and in turn were forwarded to the Phytotoxicology Section, Air Resources Branch for investigation. As these concerns also had been expressed directly to staff at the Ontario Hydro plant in Nanticoke, a meeting was arranged by the Corporate Relations Division (Western Region) of Ontario Hydro to review the matter and determine the manner in which they would be investigated.

According to Ontario Hydro the two main concerns were as follows:

1. farmers are now unable to grow some sensitive crops (spring grains) in the vicinity of the industrial complex
2. yields of crops that are grown have gone down due to airborne emissions from the complex.

Some concern also was raised about the trend of increasing soil acidity in the area as a result of acid washout during rain events.

It was subsequently pointed out to Hydro personnel that two official vegetation complaints had been received by the MOE, and, in accordance with the Environmental Protection Act, 1971, the farmers had been contacted by the Phytotoxicology Section and informed that an investigation would be conducted and written reports prepared for distribution to the complainants.

As a matter of background to the issue, similar complaints of spring grain problems in the Nanticoke area had been received and investigated by the Phytotoxicology Section in 1980 and 1982. The 1980 investigation, involving both MCE and Ontario Ministry of Agriculture and Food (OMAF) personnel, was conducted at the request of Mr. Gordon Miller (MPP), throughout the Haldimand County area in response to concerns about air pollution damage to spring grains (oats, barley). No air pollution injury was found. The poor growth and late development which was observed was attributed to cold and wet weather in the spring of 1980.

In 1982 another investigation by the Phytotoxicology Section revealed that the growth of barley throughout the Haldimand clay belt was poor and was related to soil and disease problems. In a separate investigation of this problem the OMAF Soils and Crops

Specialist requested assistance from the Department of Land Resource Science at the University of Guelph and the conclusion reached was that the problem was related to nitrogen deficiency induced by adverse weather conditions (cold, wet) which rendered the nitrogen unavailable for plant growth. Thus, the two separate investigations reached similar conclusions.

In view of the negative findings from previous investigations and the continued concern from numerous farmers in the area regarding the effect of emissions from the industrial complex on crop growth it was apparent that a full scale study was required.

It was proposed that Mr. Harold Bentley, Agricultural Representative Haldimand County who also serves as Secretary to the Haldimand County Soils and Crop Improvement Association and is familiar with the farmers of the area, would be a logical choice as a co-ordinator to draw together a team of specialists from both OMAF and MOE to investigate the crop problems in 1985. The other advantage would be the communication possibilities through the Soils and Crop Improvement Association to get feed-back on the study and to keep the growers informed of progress.

Accordingly, the study was initiated with the following three principal investigators:

- Mr. Harold Bentley: Agricultural Representative, Haldimand
County - Ontario Ministry of Agriculture
and Food - Cayuga.
- Mr. Ron Pearson: Supervisor, Soils and Vegetation Assessment
Unit, Phytotoxicology Section - Ontario
Ministry of Environment - Toronto.
- Mr. Bruce Archibald: Soils and Crops Specialist, Plant Industry
Branch - Ontario Ministry of Agriculture
and Food - Simcoe

Assistance was solicited and obtained from the following groups/organizations:

1. Local farmers
2. Crop Insurance Commission - OMAF
3. West Central Region - MOE
4. Air Quality and Meteorology Section - MOE
5. Ontario Hydro - Nanticoke

C. STUDY OUTLINE

After several planning sessions the following study outline was formulated for the spring grain investigation in 1985.

1. a complete literature review to assess the sensitivity of cereals to SO_2
2. a thorough work-up of all historical SO_2 data in the vicinity to the N and NE of the industrial complex and a comparison of these data with the corresponding 1985 results
3. a review of historical barley yield data in the vicinity to the N and NE of the industrial complex from available Crop Insurance Commission records
4. a thorough work-up of all available weather data in the vicinity to the N and NE of the industrial complex and a comparison of the data with the corresponding 1985 results
5. selection of study sites for 1985 based on a common soil type (Haldimand clay) with sites located to the N, NE and in a remote control location - 15 sites total

6. preparation of a detailed crop production management questionnaire for distribution to all growers selected for study
7. a visit to each site in late May to collect soil samples from all barley fields and, in each case, from an adjacent undisturbed fence row for multi-element and general fertility analysis
8. a visit to each site in early July to take barley tissue samples for nutrient analysis
9. a visit to each site in mid-July to take barley foliage samples for multi-element analysis, to collect data on soil and crop physical characteristics and to examine plant foliage for visible SO₂ injury symptoms
10. a visit to each site in late July/early August to harvest barley for yield determination
11. analysis of all crop, soil, weather and SO₂ data and preparation of a final report
12. presentation of results to all interested groups

D. REVIEW OF SO₂ - PLANT RESPONSE LITERATURE

Because of their relatively high sensitivity to SO₂, their importance in agricultural production and their common occurrence throughout most of North America, cereal grains (barley, oats, wheat) have been the subject of numerous investigations reported in the scientific literature. This section presents a brief summary of the findings from most of the more recent studies containing information on the SO₂ dose - response relationship. The details on each study have been

partitioned into foliar injury and growth/yield effects and are presented in Table 1.

In order to evaluate the various studies in terms of defining a general threshold dose-response pattern, the data where threshold or minimal foliar injury/yield effects were reported have been extracted from Table 1 and concentration-time regressions have been run. The curves are depicted in Figures 1 and 2. From the highly significant concentration-time relationships which were apparent for both foliar injury and yield the regression equations were used to prepare the following predicted dose-response values:

TABLE 2

DOSE RESPONSE RELATIONSHIP FROM LITERATURE REVIEW
FOR SO₂ CONCENTRATION AND DURATION RESULTING IN
THRESHOLD OR MINIMAL FOLIAR INJURY AND YIELD/GROWTH
EFFECTS FOR CEREALS

Duration of Exposure (hr)	Predicted* SO ₂ Concentration** Required For	
	Threshold or Minimal Effects	
	Foliar Injury	Yield/Growth Effects
	-----ppb-----	
1	650	1000
2	550	900
4	500	850
8	450	750
12	400	700
24	300	600
168 (1 wk)	150	350

* Regression Equations Foliar Injury $Y = -97.4 \ln X + 633.6$
(see Figs 1 and 2) (F = 26.5 p ≤ 0.01)

Yield/Growth $Y = -131.2 \ln X + 1011.7$
(F = 23.4 p ≤ 0.01)

where Y = SO₂ (ppb)
X = Exposure duration (hrs)

** Concentration (ppb - rounded to nearest 50 ppb)

In 1961, Van Haut reported that yield loss in cereals and other crops depended on the growth stage of the plant at the time of pollutant exposure. For cereals the greatest yield losses (1000 grain seed weight) were observed when plants were exposed at the flowering stage. No details are available concerning the exposure characteristics which were used. However, in another recent study under more realistic field conditions (Wilhour et al., 1979) it was found that short duration exposures (3 hours) ranging from 250-1200 ppb had no effect on barley or wheat yields regardless of the stage of plant development. They (Wilhour et al., 1979) also found that varying the frequency of 3 hour exposures (250-1200 ppb) ranging from once per week to once every 5 weeks had no effect on the severity of foliar injury or on crop yield.

From a seasonal aspect under field conditions Roberts, (1984) has summarized all available field studies and concludes that where fumigation occurs for about 10% of the growth period the SO_2 mean during fumigations must be in excess of 185 ppb to affect yields of most sensitive crops with a 2.5 percentile of at least 260 ppb.

E. SO_2 MONITORING RESULTS - NANTICOKE AREA

The area to the N and NE of the Nanticoke industrial complex has been extensively monitored since the commissioning of the Ontario Hydro generating station in the mid-1970s. In order to assess possible SO_2 emission effects on spring grains, air monitoring stations located in the N and NE sector, in the vicinity of the barley study sites were utilized in a summary from 1975-1985. As only 5 of the numerous sites in this area have been operated continuously through this 11 year span, the annual averages were determined using a varying number of monitoring sites each year. This permitted the inclusion of a greater number of monitoring stations with the criterion for

inclusion in the summary table being that the station had operated continuously for at least 7 of the 11 years.

The location of the monitoring stations is shown in Fig. 3 and the results are presented in Table 3. The averages were calculated using a 5 month growing season basis on both a 12 (0800-1900) and 24 hour basis. The average number of exceedances of 1 hr (250 ppb) and 24 hr (100 ppb) MOE criteria are shown and the data have been assessed on a frequency percentile basis (1, 3, 5 and 10%) to permit comparison with the dose-response information reported in the literature review.

In order to assess the possibility of major differences on a month to month basis during the growing season the average 24 hour means and 3 percentile values were evaluated on a month by month averaging basis using the 5 stations which have run continuously through the 11 year period. The results are presented as 1975-85 averages and, for comparison 1985 alone. These values are presented in Table 4.

From Table 3 it is apparent that on both a 12 and 24 hour basis the average SO_2 growing season averages are all well below the MOE annual average criterion of 20 ppb. They also reveal very minimal year to year variation with 12 and 24 hr mean ranges of 3.6-6.3 and 2.5-4.2 ppb, respectively. The maximum 12 and 24 hour means also are fairly uniform throughout the 11 year period and, in the case of the average 24 hour maximum values, the highest one 35.2 ppb (1984) is still well under half of the corresponding MOE criterion of 100 ppb. On an hourly basis it is apparent that the MOE criterion (250 ppb) is exceeded occasionally each year throughout the study area. The highest average hourly values range from 155-254 ppb during daylight hours (12 hour basis) and from 157-270 ppb on a 24 hour basis.

The average number of exceedances of the 1 hour MOE criterion throughout the study area amounts to about once during the growing season. The 24 hour criterion has never been exceeded.

The frequency percentiles reveal that during the growing season fumigations resulting in hourly SO_2 levels at or above 10 ppb occur approximately 10% of the time with levels above 30-50 ppb occurring about 1% of the time. With the exception of the 1 percentile values for 1978 and 1979 there has been no difference in the frequency distribution pattern from 1975-1985.

On a monthly basis (Table 4) it is apparent that over the 11 year period the severity and frequency of SO_2 fumigations varies little over the 5 month growing season. This uniform pattern also was apparent in 1985.

F. COMPARISON OF AIR MONITORING RESULTS WITH DOSE RESPONSE AND HISTORICAL BARLEY YIELDS

A comparison of the predicted SO_2 concentrations required to cause threshold or minimal foliar injury or growth/yield effects with the actual monitoring results from the Nanticoke spring grain study area is shown in Table 5 below.

TABLE 5

COMPARISON OF DOSE-RESPONSE INFORMATION FOR CEREALS
WITH ACTUAL MONITORING RESULTS IN THE NANTICOKE
SPRING GRAIN STUDY AREA: 1975-1985

Exposure Duration (hours)	Threshold or Minimal Effects Concentration from Literature*		Actual Monitoring Results** for Nanticoke Area		
	Foliar Injury	Yield/ Growth Effects	Ave. Maximum for All Years (All Stations)	Ave. Maximum for Any One Year (All Stations)	Maximum for Any One Year (One Station)
1	650	1000	212	270	710
12	400	700	46	61	106
24	300	600	26	35	56
2.5 per- centile (approx. 90 hours)	-	≥260	≥24 ^a	≥31 ^a	≥80 ^a

a Nanticoke percentile shown is 3% (approx. 110 hrs)

* Levels taken from Table 2 and from text of Literature Review

** Levels taken from Table 3 except last column which were extracted from the raw monitoring data (13 stations)

It is apparent from this comparison that SO₂ growing season exposure conditions throughout the study area have posed no threat to the successful growth of cereal crops over the past 11 years. The only instance where a single, 1 hour level exceeded the predicted foliar injury threshold was in 1978 (NNE09). This level of 710 represents one excursion in over 500,000 monitoring hours as the next 2 highest individual hourly values were 590 ppb (NNW08-1977) and 560 ppb (NNW03-1979) both below the 1 hour foliar injury threshold.

In order to further assess any potential impact of SO₂ exposure on barley yields in the Nanticoke study area historical data from Crop Insurance Commission records were obtained for

each year (Table 6) and statistical correlations were run with the various SO₂ exposure parameters in Table 3. The results of this comparison are shown in Table 7. In no case were any significant relationships apparent, thereby confirming the conclusions reached from the literature search.

G. FIELD INVESTIGATION ITINERARY (MOE and OMAF)

On May 30, 31 and June 3, 1985 MOE and OMAF established 12 barley study plots in the area to the N(6) and NE(6) of the Ontario Hydro generating station (the largest SO₂ emission source in the Nanticoke industrial complex). All sites were located on the Haldimand clay soil type. For control purposes, three sites were established to the ENE at a distances ranging from 25-35 km. This area was selected because of its similar soil classification, its location relative to the shore of Lake Erie (similar meteorological patterns) and its distance from Nanticoke. All sites are shown in Fig 4 with full details on the study sites in Table 17. During the initial investigation soil samples from the 0-15 cm depth throughout each barley field were collected for separate analysis by both the MOE and OMAF Laboratories. In addition, a sample of soil from the 0-15 cm depth was collected at each site from a nearby undisturbed fence row for comparative analysis at the MOE laboratory. This was done to evaluate the effect of cultural practices on the soil chemistry parameters.

In addition to the initial selection of the 15 study sites and the preparation and distribution of a detailed agronomic questionnaire to all participants in the study, OMAF personnel re-visited all sites in early July to collect foliar samples at the flag leaf stage for tissue analysis (nutrient status).

A full scale foliar analysis collection was made at each site by MOE staff on July 10-11, 1985. During this investigation samples of whole barley plants were dug up at each site (6

different locations) and returned to the Phytotoxicology Laboratory for full scale measurement of their physical growth characteristics. Six samples of soil also were collected at each barley site for an analysis of various physical parameters.

The final visit to the Nanticoke area was by OMAF staff during the week of July 22-26. At this time all study sites were hand harvested for grain yield determination.

H. DISCUSSION OF RESULTS

H.1 MOE FINDINGS

H.1.1 Soil Analyses Results

The analytical results for 23 inorganic parameters at both the field and fence row locations for all 15 study sites are shown in Table 8. The field and fence row data have been further compared in Table 9. In an attempt to identify possible distance or directional effects the raw soil data from each site were further compared in a statistical manner. This comparison is shown in Table 10. As a final check on the relevance of the soils data to the growth of the barley crop, the barley yield data from each study site were utilized in correlation analyses with each of the soil parameters. The results of this analysis are shown in Table 11.

An evaluation of the soil analytical results in Table 8 reveals no major inorganic accumulations which would signify deposition from the industrial complex or problems with respect to crop productivity. In comparing the field and fence row data (Table 9) it is apparent that over the years, cropping the land has resulted in a noticeable increase in soil sulphates, copper and iron while levels of organic carbon, extractable potassium, total nitrogen

and total zinc have decreased. As these trends were apparent throughout both the N and NE sectors and at the control sites, they reflect general management practices and are unrelated to emissions from the Nanticoke complex.

When the data were evaluated for both a directional and proximity effect (Table 10) the results in almost all cases failed to reveal any statistical relationship. The few exceptions to this general finding are shown in Table 10. Within the barley fields zinc levels at the most distant sites (Nos. 6-10, 12, 14-16) were significantly higher than those located closest to the source (Nos. 2, 3, 5). On a directional basis selenium was found to be significantly higher in soils from the N and NE sectors (Nos. 1-12) compared to the control area (Nos. 14-16). In the case of fence row samples antimony tended to be higher at the mid-distance sites (Nos. 1, 4, 11) compared to the most distant ones (Nos. 6-10, 12, 14-16) and also higher in the NE sector (Nos. 2, 1, 4, 12, 6, 7) compared to the control area (Nos. A-16).

In the final comparison all soils data from the field locations were correlated with the hand harvest yield data to determine the biological significance of the chemical concentrations. The correlation coefficients are shown in Table 11 and, with the exception of available magnesium and total mercury, fail to reveal any relationship between the concentration of the various elements and barley yield. In the case of mercury, highest yields were found at sites with the highest soil mercury levels, while with available magnesium a reverse (negative correlation) effect was apparent. These two exceptions do not appear to be important in terms of establishing a cause effect relationship with emissions from the industrial complex.

H.1.2 Foliar Analyses Results

The barley foliage analyses results for 22 inorganic parameters at all 15 study sites are shown in Table 12. As was the case with soil these data were statistically evaluated for both a distance and directional effect (Table 10) and for any relationship with final barley yield (Table 13).

In Table 12 the data can be compared with two sets of criteria. The "Phytotoxicology Upper Limit of Normal" (ULN) has been calculated for a number of inorganic elements. It was determined by taking the arithmetic mean of all available analytical data collected in areas remote from point sources of air pollution. By adding three standard deviations of the mean the "ULN" represents the 99 percentile probability for background concentrations. The "Upper Critical Levels" (UCL) for spring barley are taken from Davis et al. (1978) who evaluated the response of young barley plants in sand culture experiments and determined the foliar threshold concentrations for yield/growth effects.

In comparing the data to these two criteria it is apparent that in the case of iron, manganese, chloride and sulphur, a few excursions of the Phytotoxicology U.L.N.'s were recorded. In contrast, none of the U.C.L.s were exceeded.

In the case of the U.L.N. excursions, the only one of any significance appears to be iron, as in all other cases exceedances also were found at the control locations or at points well remote from the industrial complex. This type of variation is not uncommon with natural plant components such as sulphur and chloride.

When the foliar data were evaluated from a distance and directional basis (Table 10) a few significant differences were apparent. Again, iron was found to be significantly higher at the closest sites (Nos. 2, 3, 5) compared to the most distance locations (Nos. 6-10, 12, 14-16).

In the final comparison of the foliar data with barley yield at each study site (Table 13) no significant correlations were apparent, indicating that crop yield was not related to the foliar concentration of any of the elements analyzed.

H.1.3 Soil and Crop Physical Characteristics

During the mid-July visit to each of the sites the physical characteristics of the soil and crop were evaluated (Tables 14, 15). In the case of the soil measurements (Table 14) it was found that in many cases the barley roots had penetrated to only a limited depth where they encountered a very hard, cemented soil matrix, referred to as a hard-pan. The bulk density (Table 14) of this compacted soil was, in most cases, (including the control sites) found to be well above normal for a clay soil and accordingly had limited the degree of root penetration. A statistical comparison (Table 16) of barley yields with the depth to the hard-pan layer confirmed that the more shallow the hard-pan layer the lower were the barley yields. The other significant soil relationship was with the percent of sand in the soil, with higher % sand associated with higher barley yields. In one other statistical evaluation of the various soil physical parameters no relationship was found with regard to the proximity or direction of study sites from the industrial complex.

In the case of the crop growth parameters (Table 15) it was found that low barley yield was statistically related to short plant height, small head weights and low root weights (Table 16). As with soil the barley physical parameters (with one exception) were not found to have been affected by either site proximity or direction from the industrial complex. The one exception was with tillering which was greater at mid-distance sites (Nos. 1, 4, 11) compared to closer or more distant fields.

H.1.4 Visual Observations

During the initial investigation (late-May) and the mid-July collection, observations were made of the general appearance of barley foliage and of the leaves of other SO₂ sensitive species growing in the area. Some of these included, clovers, alfalfa, black medic, ragweed, wild strawberry, raspberry, lamb's quarters, dandelion, wild carrot, burdock, white ash, plantain, hawthorn bird's-foot trefoil, and redroot pigweed. In no case were any symptoms found that could be attributed to an exposure to SO₂.

Samples of barley also were returned to the Phytotoxicology pathology laboratory. An examination of the leaves and roots revealed only occasional structures of Alternaria, Fusarium and Helminthosporium. No eggs, cysts lesions, or galls indicative of nematode infestation were found at any of the study sites.

H.2 OMAF FINDINGS

H.2.1 Agronomic Questionnaire

The results of the agronomic questionnaire are shown in Tables 17-19. All of the fields monitored were in the

Haldimand soil type series. No field had barley grown in the previous year. All fields with the exception of No. 9 had some sort of fall primary tillage and conventional secondary tillage in 1985 (Table 18).

H.2.2 Soil Fertility Analyses

The results of the soil fertility sampling (Table 20) which was conducted in late May found K_2O levels in the soil generally high while P_2O_5 levels were in a medium range. These results are typical of those found in the Haldimand Series. Soil pH was generally in the 6.0-6.2 range; however, some fields in the more remote South Cayuga area were more acidic.

When these results were evaluated on a distance and directional basis from the industrial complex, no significant relationships were apparent (Table 10). When compared with final barley yield (Table 11) the soil results also failed to reveal any significant association. The one exception was a trend towards higher yields with increased levels of available soil zinc.

H.2.3 Barley Tissue Test Analyses

Tissue samples taken at the flag leaf stage (Table 21) did not reveal any startling findings other than a slightly elevated iron level in barley tissue sampled in close proximity to the Nanticoke complex (statistically significant - Table 10) and generally higher levels of nitrogen and phosphorus in fields with the highest yields. In the case of N and P, this relationship with yield was found to be statistically significant (positive) (Table 13).

H.2.4 Barley Yields Results

Hand harvest yield assessments were taken in late July. These results are listed in Table 15. The average yield for the study was 77 bu/ac. This was well above the county average. As with most other crop development parameters, the final yield data did not demonstrate any relationship with either distance or direction from the industrial complex (Table 10).

H.2.5 Evaluation of Rainfall Data

Rainfall records for the past 11 years during the barley growing season show a tremendous variability from year to year and between similar months in any given year (Table 22). The total rainfall during the first 3 months of growth (April-June) was found to correlate negatively with barley yields in the Nanticoke area over this 11 year period. This relationship is depicted in a regression curve in Figure 5.

In summary it appears as though spring planting date (which is weather determined) is the single greatest factor affecting barley yield in Haldimand county. The cool temperatures and short photoperiod which generally occur in April after seeding, prolong the vegetative period in barley development. This longer growing period favours higher yields. In springs with excessive rainfall, early planting on clay ground can not be facilitated.

With this in mind, alternatives to conventional seeding practices of spring grain on Haldimand clay should be considered. Frost seeding, aerial seeding or broadcast and harrowing seeding methods have been researched in

other areas of the province and could be examined in Haldimand county in the future.

H.2.6 Visual Observations

It was possible to find low level infestations of some common barley insects and diseases throughout the season; however, none of these would be considered unusual.

I. CONCLUSIONS

On the basis of the joint OMAF-MOE investigation which was conducted in 1985 in the vicinity of the Nanticoke industrial complex following several complaints from local farmers concerning problems with the growth of spring grains, the following major conclusions can be drawn:

1. on the basis of a thorough literature review of the response of cereals to SO_2 on both a short and long term basis and a comparison with corresponding SO_2 monitoring data over the past 11 years there is no basis for any concern regarding the levels of SO_2 experienced in this area.
2. an evaluation of the barley growth and yield information gathered from the 15 study sites in 1985 failed to find any relationship with sampling proximity or direction from the industrial complex nor with the majority of the soil or foliar chemistry parameters. The few exceptions to these findings appeared to be related to agronomic or fertility practices at a few of the study sites.
3. an evaluation of soil and barley foliar chemical parameters on a distance and directional basis revealed a very minor degree of foliar contamination at some sites located closest

to the industrial complex; however, as indicated in conclusion 2, these elevations had no effect on crop yield.

4. Soil acidity levels throughout the study area were found to be within an acceptable range and no evidence of any acid rain washout effects were apparent.
5. from an agronomic aspect it was found that the heavy clay soils in this area are prone to severe hard-pan formation and to adverse weather conditions (rainfall); in this regard, spring planting date appears to be the single greatest factor affecting barley yield, as in springs with excessive rainfall, early planting on clay ground cannot be facilitated. Hard-pan formation also restricts root penetration and can result in drought stress during critical mid and late season periods in the development of the crop.

J. REFERENCES CITED

Davis, R.D., Beckett, P.H.T. and E. Wollan. 1978. Critical Levels of Twenty Potentially Toxic Elements in Young Spring Barley. Plant and Soil 49 : 395-408.

Guderian, R. 1977. Air Pollution: Phytotoxicity of Acidic Gases and Its Significance in Air Pollution Control. Ecological Studies 22. Springer-Verlag. Berlin, Heidelberg, New York. pp. 127

Guderian, R. and H. Stratmann. 1962. Freilandversuche zur Ermittlung von Schwefeldioxidwirkungen auf die Vegetation - I. Teil: Übersicht zur Versuchsmethodik und Versuchsauswertung, Köln und Opladen, Westdeutscher Verlag, Forsch. Ber. d. Landes Nordrhein - Westfalen Nr. 1118.

- Lawrence, J.A. 1979. Response of Maize and Wheat to Sulfur Dioxide. Plant Dis. Reptr. 63 : 468-471
- Mandl, R.H., Weinstein, L.H. and M. Keveny. 1975. Effects of Hydrogen Fluoride and Sulphur Dioxide Alone and in Combination on Several Species of Plants. Environ. Pollut. 9 : 133-143.
- Pande, P.C. 1985. An Examination of the Sensitivity of Five Barley Cultivars to SO₂ Pollution. Environ. Pollut. (Ser. A) 37 : 27-41.
- Pande, P.C. and T.A. Mansfield. 1985a. Responses of Winter Barley to SO₂ and NO₂ Alone and in Combination. Environ. Pollut. (Ser. A) 39 : 281-291.
- Pande, P.C. and T.A. Mansfield. 1985b. Responses of Spring Barley to SO₂ and NO₂ Pollution Environ. Pollut. (Ser. A) 38 : 87-97
- Roberts, T.M. 1984. Effects of Air Pollutants on Agriculture and Forestry. Atmos. Env. 18 : 62-652.
- Swain, R.E. and A.B. Johnson. 1936. Effect of Sulfur Dioxide on Wheat Development. Ind. Eng. Chem. 28 : 42-47.
- Van Haut, H. 1961. Staub 21 : 52-56
- Wilhour, R.G. Neely, G.E., Weber, D.E. and L.C. Grothaus. 1979. Response of Selected Small Grains, Range Grasses and Alfalfa to Sulfur Dioxide. Paper No. 79-13.6 at 72nd Annual Meeting of Air Pollution Control Assoc., Cincinnati, Ohio, June, 1979.
- Zahn, R. 1961. Effects of Sulfur Dioxide on Vegetation: Results of Gas Exposure Experiments. Staub 21 : 56-60.

TABLE 1

23

SUMMARY OF LITERATURE SURVEY CITINGS FOR SO₂ EFFECTS ON CEREALS

CROP SPECIES	SO ₂ DOSE AND EXPOSURE PARAMETERS	EFFECTS/CONCLUSIONS		AUTHOR(S)
		FOLIAR INJURY	YIELD/GROWTH	
Wheat	- In chambers - daylight hr 200-300 ppb for 150 hrs (17 days)	this exposure was threshold for foliar injury	-	Zann, 1961
	250 ppb for 160 hr (18 days)	-	- effects on shoot growth found at these exposures	
	500 ppb for 125 hr (14 days)			
	1000 ppb for 65 hr (7 days)			
Wheat	300 ppb for long periods of time	no foliar injury	-	Swain and Johnson, 1936
Spring Barley	20 day old plants in chamber	marginal and terminal necrosis after 72 hr at 300 ppb, 120 hr at 150 ppb and 14 days (336 hr) at 60-80 ppb	-	Mandi et al., 1975
	120, 300 ppb for 7 days			
	continuous			
Winter Wheat	60-80 ppb for 14 days			
	continuous			
Winter Wheat	field plots in vicinity of SO ₂ source		10% yield decrease with a mean of 180 ppb during fumigation periods (10-15% of time) and a 2.5 percentile of 265 ppb	Guderian and Stratmann, 1962
			7-17% yield decrease for winter rye, oats and spring wheat with a mean of 240 ppb during fumigation periods (18-23% of time and a 2.5 per- centile of 525 ppb	

TABLE 1 (cont'd)

SUMMARY OF LITERATURE SURVEY CITINGS FOR SO₂ EFFECTS ON CEREALS

CROP SPECIES	SO ₂ DOSE AND EXPOSURE PARAMETERS	EFFECTS/CONCLUSIONS		AUTHOR(S)
		FOLIAR INJURY	YIELD/GROWTH	
Spring Wheat and Winter Wheat	200, 400 and 600 ppb for 30, 78 and 100 hr in chambers	- trace amounts of leaf injury even at lowest dose (200 for 30 hr)	only significant dry wt. reduction was in 1 variety of winter wheat at 600 ppb for 100 hr	Laurence, 1979
	- 2 week old plants	- spring wheat varieties tended to be more resistant than winter		
Spring Barley	100 ppb continuously for 20 days in chambers	trace amounts of terminal and marginal injury on older leaves after 8 days (192 hr)	20.2% reduction in root dry wt. and 19.3% reduction in leaf dry wt. (due to reduction in tillering)	Panda and Mansfield, 1985b
Spring Wheat, Oats	field exposure in pots near an SO ₂ source range in exposure from 230 ppb during exposure periods (5% of time) with a seasonal mean of 15 ppb to 380 ppb during exposure periods (15% of time) with a seasonal mean of 50 ppb		the threshold range for yield effects	Guderian, 1977

TABLE 1 (cont'd)

SUMMARY OF LITERATURE SURVEY CITINGS FOR SO₂ EFFECTS ON CEREALS

CROP SPECIES	SO ₂ DOSE AND EXPOSURE PARAMETERS	EFFECTS/CONCLUSIONS		YIELD/GROWTH	AUTHOR(S)
		FOLIAR INJURY			
Spring Barley	40, 80, 120 ppb continuous for 3 wks. (504 hrs)			- 80 and 120 ppb significantly reduced growth of all plant parts in all cultivars	Pande, 1985
	- started 2 days after germination - chambers)			- 40 ppb significantly reduced leaf and root wt. and leaf area in 2 cultivars	
				- depression of growth in winter months	
Winter Barley	- outdoor glasshouse fumigations				Pande and Mansfield, 1985a
	93 ppb for 103 hr/wk (weekly mean = 62 ppb)			- no effect on spike wt. or 1000 grain wt.	
	- continuous for 11 months			- roots more sensitive than tops	
Spring Wheat Durham Wheat Spring Wheat	Chronic Exposure 30, 50, 100, 150 ppb for 72 hr continuous each week for 12 weeks	after 8th wk of exposure (576 hr of SO ₂) % foliar injury was:		results suggest that yield of wheat and barley can be reduced by weekly exposure to 100-150 ppb	Withour et al., 1979
	- field plots covered with chamber during fumigation	Species	30 50 100 150 ppb		
	- treatments started 3 wks after seeding	W. Wheat	5 10 15 25%		
		S. Wheat	5 15 15 20%		
		Barley	15 10 15 35%		

TABLE 1 (cont'd)

SUMMARY OF LITERATURE SURVEY FINDINGS FOR SO₂ EFFECTS ON CEREALS

CROP SPECIES	SO ₂ DOSE AND EXPOSURE PARAMETERS	EFFECTS/CONCLUSIONS		AUTHOR(S)																										
		FOLIAR INJURY	YIELD/GROWTH																											
Spring Wheat Durham Wheat Spring Wheat (cont'd)	<u>Multiple Exposure</u> 250, 400, 800, 1200 ppb for 3 hr duration every wk, 2nd wk, 3rd wk, 4th wk, or 5th wk for 12 wks.	- frequency of exposure had no effect on foliar injury - after 7th wk of exposure ave. % foliar injury was: <table><tr><th>Species</th><th>250</th><th>400</th><th>800</th><th>1200 ppb</th></tr><tr><td>W. Wheat</td><td>7</td><td>10</td><td>22</td><td>35%</td></tr><tr><td>S. Wheat</td><td>4</td><td>9</td><td>18</td><td>32%</td></tr><tr><td>Barley</td><td>4</td><td>12</td><td>26</td><td>47%</td></tr></table>	Species	250	400	800	1200 ppb	W. Wheat	7	10	22	35%	S. Wheat	4	9	18	32%	Barley	4	12	26	47%	varying the frequency of 3 hr exposures (250-1200 ppb) ranging from once per wk to once every 5 weeks had no effect on yield	Wilhour et al., 1979						
Species	250	400	800	1200 ppb																										
W. Wheat	7	10	22	35%																										
S. Wheat	4	9	18	32%																										
Barley	4	12	26	47%																										
	<u>Growth Stage Exposure</u> 1 3 hr exposure (morning) at 250, 400, 800, 1200 ppb at 6 growth stages (2 week interval)	-	- no sig. dif. in yield between growth stages for 400, 800 or 1200 ppb - sensitivity of plants to SO₂ was not affected by growth stage																											
Oats	A 500, 1000, 2000, and 4000 ppb for 1.5 hr at 14 and 21 days old (2 exposures) B 750, 1500 and 3000 ppb for 1.5 hr at 32 and 34 days old (2 exposures) C 400, 800 and 1600 ppb for 3 hr at 31, 33, 38 and 40 days old (4 exposures)	% foliar injury was: <table><tr><th>A</th><th>500</th><th>1000</th><th>2000</th><th>4000 ppb</th></tr><tr><td>1</td><td>5*</td><td>26*</td><td>58*</td><td>58*</td></tr></table> <table><tr><th>B</th><th>750</th><th>1500</th><th>3000</th></tr><tr><td>2*</td><td>10, 16*</td><td>28, 49*</td><td></td></tr></table> <table><tr><th>C</th><th>400</th><th>800</th><th>1600</th></tr><tr><td>1</td><td>28*</td><td>65*</td><td></td></tr></table> (* = significant at 95% level)	A	500	1000	2000	4000 ppb	1	5*	26*	58*	58*	B	750	1500	3000	2*	10, 16*	28, 49*		C	400	800	1600	1	28*	65*		- biomass reductions at 1000 and 750 ppb after (2) 1.5 hr exposures and 400 ppb for (4) 3 hr exposures - plants recovered if exposed early (young) - exposure at increasing maturity (B) resulted in more root vs top reductions	Hack and Dunning, 1977
A	500	1000	2000	4000 ppb																										
1	5*	26*	58*	58*																										
B	750	1500	3000																											
2*	10, 16*	28, 49*																												
C	400	800	1600																											
1	28*	65*																												

TABLE 3

27

SUMMARY OF AIR QUALITY MONITORING RESULTS (SO₂) FOR THE NANTICOKE SPRING GRAIN STUDY AREA: 1975-1985

YEAR	MONITORING STATIONS USED NO.	AVERAGE* SO ₂ LEVELS: APRIL - AUGUST (PPB)					AVERAGE* NO. EXCEEDANCES		AVERAGE* FREQUENCY PERCENTILES ** (PPB)			
		12 HOUR BASIS (0800-1900 EST)		24 HOUR BASIS			24 HOUR BASIS		24 HOUR BASIS			
		AVE. OF ALL 12 HR MEANS	MAX 12 HR MEAN	MAX 1 HR	AVE. OF ALL 24 HR MEANS	MAX 24 HR MEAN	1 HR >250 ppb	24 HR >100 ppb	10	5	3	1 %
1975	N07, N15, NNE09, NNE16, NE19, ENE11, ENE18, NNW08 (8)	3.6	45.2	205	2.5	24.5	1	0	9	13	20	30
1976	ditto 1975 + E05, NNW03 (10)	4.6	45.3	196	3.3	25.6	1	0	10	17	21	30
1977	ditto 1976 (10)	4.6	41.0	185	3.3	26.1	<1	0	10	16	27	35
1978	ditto 1977 + NNE10, NNE20 (12)	6.3	52.2	250	4.2	27.0	1	0	12	18	31	50
1979	ditto 1978 + (13)	5.7	52.6	244	3.8	29.5	1	0	12	18	28	42
1980	ditto 1979 (13)	4.6	38.7	196	2.9	21.7	<1	0	10	15	24	31
1981	ditto 1979 (13)	4.1	50.3	225	2.7	28.1	1	0	10	16	22	31
1982	ditto 1979 (13)	5.2	42.8	190	3.7	23.3	1	0	10	16	23	33
1983	ditto 1979 (13)	4.8	38.1	155	3.6	25.5	1	0	10	16	21	30
1984	N07, N15, NNE16, NE19, E05, NNW08, NNE10, NNE20, NNE05 (9)	5.4	60.6	254	4.0	35.2	1	0	10	16	22	31
1985	ditto 1984 (9)	5.3	39.7	169	3.7	23.2	<1	0	10	15	23	33
AVE. ALL YEARS		4.9	46.0	206	3.4	26.3	1	0	10	16	24	34

* Average of all monitoring sites each year

** % of monitored time that hourly SO₂ levels (ppb) were at or above the value shown

TABLE 4

COMPARISON OF AIR QUALITY MONITORING RESULTS (SO₂)
FOR THE NANTICOKE SPRING GRAIN STUDY AREA ON A MONTHLY BASIS

AVERAGING PERIOD (YRS)	AVERAGE* SO ₂ CONCENTRATION ON 24 HOUR BASIS FOR 5 MONITORING STATIONS (ppb)									
	AVE. OF ALL 24 HR MEANS					FREQUENCY PERCENTILE (3%)**				
	APR	MAY	JUN	JUL	AUG	APR	MAY	JUN	JUL	AUG
1975-85	3.2	3.5	3.6	3.5	3.4	22	24	25	27	25
1985	4.1	3.5	3.7	3.9	4.1	23	18	23	24	24

* Average of 5 monitoring stations which have operated continuously from 1975-85 (N07, N15, NE19, NNW08)

** 3% of monitoring time SO₂ hourly levels at or above values shown

TABLE 6

HISTORICAL COMPARISON OF BARLEY YIELD 1975-1985

Year	Barley Yield	
	Nanticoke Area*	Haldimand/Norfolk County**
	----- (bu/ac) -----	
1975	36	45
1976	18	28
1977	20	48
1979	40	52
1980	30	55
1981	22	53
1982	27	55
1983	25	37
1984	17	40
1985	55	53

* locations to the NE and NW of industrial complex (Crop Insurance Records)

** County averages from Agricultural Statistics for Ontario

TABLE 7

RELATIONSHIP BETWEEN AVERAGE GROWING SEASON (APRIL-AUGUST)
SO₂ AIR QUALITY LEVELS AND HISTORICAL BARLEY YIELDS
IN THE NANTICOKE SPRING GRAIN STUDY AREA: 1975-1985

Parameter Tested	Correlation Coefficient	Statistical Significance
A. 12 Hour Basis (0800-1900 EST)		
- Ave. of all 12 hr means	0.162	n.s.
- Max. of 12 hr mean	-0.281	n.s.
- Max. 1 hr value	-0.209	n.s.
B. 24 Hour Basis		
- Ave. of all 24 hr means	0.048	n.s.
- Max. 24 hr. mean	-0.393	n.s.
- Max. 1 hr	-0.148	n.s.
- No. 1 hr Exceedances (>250 ppb)	-0.263	n.s.
- No. 24 hr Exceedances (>100 ppb)	N/C	-
Frequency Percentiles*		
- 1% of hr values	0.176	n.s.
- 3% of hr values	0.105	n.s.
- 5% of hr values	-0.245	n.s.
- 10% of hr values	0.130	n.s.

N/C - not calculated as all values = 0

* within each percentile (% of monitoring time basis) correlations run on the average concentration which was equalled or exceeded each year (ave. of all monitoring sites) and historical barley yield

SUMMARY OF SOIL ANALYSES RESULTS FOR SAMPLES COLLECTED IN THE MANTOQUE SPRING GRAIN STUDY AREA
- MAY 30, 31 & JUNE 3, 1985

Location	Type*	Sector	Chemical Concentration of Soil (0-15cm)																SEC Meq/100g						
			Al	As	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Sb	Se	V	Zn	pH H ₂ O	pH CaCl ₂		Ca ^b	Mg ^b	K ^b	Al ^b	SO ₄ ^b	M
(ppm - dry wt basis)																									
Site 5	b	N	25000	4.81	1.4	32	17	28000	0.03	1	21	25	0.22	0.93	51	73	6.8	6.0	2300	440	160	2	25	1.4	15
	f		25000	4.93	1.5	30	15	27000	0.04	1	20	24	0.22	0.96	47	74	5.9	5.1	1900	560	250	3	25	1.9	13
Site 3	b	O	31000	5.04	1.4	39	21	33000	0.04	1	28	28	0.30	0.51	56	78	6.4	5.7	2300	550	160	3	20	1.3	15
	f		27000	5.04	1.6	34	19	29000	0.04	1	25	26	0.22	0.72	50	84	7.2	6.6	2800	260	250	5	16	1.8	17
Site 11	b	R	28000	5.04	1.5	40	19	31000	0.03	1	26	25	0.22	0.40	53	73	7.2	6.4	2300	420	140	2	26	1.3	15
	f		28000	4.81	1.4	38	18	29000	0.05	1	25	25	0.20	0.40	50	110	6.1	5.5	2900	560	360	3	22	2.8	18
Site 9	b	T	32000	5.35	1.8	43	29	36000	0.04	1	31	30	0.22	0.93	59	100	6.6	6.3	3800	420	290	3	83	2.5	23
	f		31000	4.19	1.6	39	21	31000	0.04	1	26	27	0.22	1.33	54	88	6.4	5.7	3500	450	240	2	34	3.0	22
Site 8	b	H	31000	4.42	1.5	39	20	33000	0.04	1	27	34	0.30	0.93	55	86	7.2	6.8	3500	360	300	2	26	1.9	21
	f		31000	4.58	1.8	40	26	33000	0.04	1	27	31	0.22	1.04	56	110	7.6	7.2	4400	310	270	2	19	2.6	26
Site 10	b		27000	4.58	1.4	36	24	30000	0.05	1	25	26	0.22	0.93	51	78	6.9	6.4	2200	290	140	2	40	1.6	14
	f		25000	4.42	1.5	35	17	28000	0.05	1	22	25	0.22	1.40	49	81	6.7	6.0	2400	250	200	5	12	2.2	15
Site 2	b	M	29000	4.96	1.7	36	17	30000	0.03	1	24	25	0.30	0.72	55	69	6.7	5.8	1600	400	200	2	28	1.1	11
	f		30000	4.66	1.5	34	16	29000	0.05	1	22	25	0.30	0.72	55	82	6.2	5.5	2500	460	240	7	23	2.0	17
Site 4	b	O	32000	4.58	1.8	41	26	35000	0.04	1	30	29	0.22	0.72	58	85	7.5	7.0	3200	290	170	3	22	1.6	19
	f		31000	9.71	1.5	38	22	32000	0.03	1	27	28	0.40	1.53	55	82	6.4	5.5	2400	380	240	2	20	1.8	16
Site 1	b	T	28000	4.66	1.5	37	19	31000	0.03	1	25	26	0.30	0.72	52	74	5.9	5.1	2100	380	190	5	37	1.2	14
	f		26000	5.20	1.4	35	21	31000	0.03	1	22	27	0.30	1.03	51	78	5.9	5.1	1900	350	220	2	22	1.8	13
Site 12*	b	H	31000	5.43	1.6	41	19	35000	0.03	1	29	31	0.20	0.40	57	81	5.8	5.5	2300	320	140	5	22	1.8	15
	f		28000	5.51	1.4	37	17	33000	0.04	1	25	29	0.20	0.40	55	76	6.5	5.2	2100	370	240	2	15	1.8	14
Site 6	b	A	29000	5.43	1.6	37	19	34000	0.03	1	27	27	0.22	0.72	53	78	6.8	5.9	2500	520	170	2	28	1.3	17
	f		32000	5.43	1.8	41	19	34000	0.03	1	28	25	0.22	0.72	58	110	6.7	5.9	5000	560	210	2	22	1.9	18
Site 7	b	S	32000	5.20	1.9	43	22	37000	0.04	1	30	27	0.22	0.72	61	93	6.3	5.6	2700	450	250	2	43	2.2	18
	f		28000	4.96	1.6	35	18	32000	0.04	1	26	27	0.22	0.93	51	150	6.9	6.1	2900	390	240	2	20	2.2	18
Site 14	b	C	31000	5.43	1.5	39	20	34000	0.03	1	30	28	0.20	0.18	53	77	6.9	6.6	2700	380	160	2	27	1.3	17
	f		30000	5.20	1.6	41	19	34000	0.04	1	30	32	0.10	0.18	53	97	5.7	4.9	1800	410	300	15	20	1.7	13
Site 15	b	M	24000	5.51	1.5	32	14	30000	0.04	1	20	35	0.20	0.40	51	100	5.8	5.3	1300	550	160	2	33	1.6	10
	f		19000	4.42	1.2	25	9	20000	0.05	1	17	29	0.20	0.29	40	110	6.3	5.7	1800	500	220	7	22	2.5	14
Site 16	b	O	31000	4.81	1.5	40	18	32000	0.03	1	25	31	0.28	0.51	52	96	5.5	4.8	1700	520	140	18	36	2.0	13
	f		24000	4.50	1.3	33	16	28000	0.03	1	23	25	0.20	0.51	49	120	6.4	5.7	2400	570	210	2	26	2.5	17

*Type b = 0-15 cm depth from barley field

f = 0-15 cm depth from adjacent undisturbed fence row

a = extractable in sodium chloride

b = extractable in water

TABLE 9

COMPARISON* OF BARLEY FIELD AND CORRESPONDING FENCE ROW SOIL ANALYSES RESULTS FOR
SAMPLING SITES IN THE NANTICOKE SPRING GRAIN STUDY AREA - 1985

Location	General Direction	% by which Barley Field Soil Result is Higher (+) or Lower (-) than Corresponding Fence Row Sample						
		SO ₄	Cu	Fe	Organic Carbon	EXTR K	TOT. N	Zn
		<-----higher----->			<-----lower----->			
Site 5	N	0	+31	+4	-30	-30	-26	-1
Site 3		+25	+11	+14	-34	-36	-28	-7
Site 11		+18	+6	+7	-63	-61	-54	-34
Site 9		+144	+38	+16	-15	+21	-17	+14
Site 8		+37	-23	0	-35	+11	-27	-22
Site 10		+208	+41	+7	-39	-30	-27	-4
Site 2	NE	+22	+6	+10	-43	-17	-45	-16
Site 4		+10	+18	+9	-16	-29	-11	+4
Site 1		+68	-10	0	-31	-14	-33	-5
Site 12		+47	+12	+6	-8	-42	0	+7
Site 6		+27	0	0	-29	-19	-32	-29
Site 7		+115	+22	+16	-9	+4	0	-38
Ave. N and NE Sites		+60	+13	+14	-29	-21	-25	-11
Site 14	CONTROL	+35	+5	0	33	-47	-24	-21
Site 15		+50	+56	+50	-43	-27	-36	-9
Site 16		+38	+13	+14	-19	-24	-20	-20
Ave. Control Sites		+41	+25	+21	-32	-33	-27	-17
Ave. Study Area		+51	+19	+18	-31	-27	-26	-14

* Only those analyses in which a comparison between field and fence row results revealed consistently higher or lower % difference values within both the N, NE and Control Area sites were selected for presentation. Average differences below 10% were not considered significant.

TABLE 10

STATISTICAL EVALUATION RESULTS FOR ALL SOIL AND BARLEY FOLIAGE
CHEMICAL AND PHYSICAL PARAMETERS - 1985

Parameters Evaluated	Statistical Significance ¹ (F-Test)	
	Distance ²	Direction ³
<u>MOE Soil Analyses</u>		
- barley fields	Zn(D-3>D-1)*	Se(N, NE>Control)*
- fence rows	Sb(D-2>D-3)*	Sb(NE>Control)* Mg(Control>N, NE)**
<u>OMAF Soil Analyses</u>		
- barley fields	none significant	none significant
<u>Soil Physical Properties</u>	none significant	none significant
<u>MOE Barley Foliage Analyses</u>		
	Fe(D-1>D-3)*	B(N>Control)*
	Al(D-1>D-3)*	Mo(N>NE, Control)*
	B(D-1>D-2, D-3)**	Ti(Control>N)*
	Cr(D-1>D-3, D-2)**	
	Pb(D-1>D-3)*	
<u>OMAF Barley Tissue Analyses</u>		
	Fe(D-1>D-3)*	Mn(Control>N, NE)*
	Zn(D-3>D-1)*	
<u>Barley Growth Parameters</u>		
	No. Tillers (D-2>D-3, D-1)**	none significant
<u>Barley Yield</u>		
	not significant	not significant

¹ only those parameters with a significant (*p≥95%) or highly significant (**p≥99%) F-Test result are shown; all other comparisons were non-significant (p<95%).

² Distance: all data separated into three distance categories as follows
D-1 - Sites 2, 3, 5
D-2 - Sites 1, 4, 11
D-3 - Sites 6, 7, 8, 9, 10, 12, 14, 15, 16

³ Direction: all data separated into three direction categories as follows:
N (Sites 3, 5, 11, 8, 9, 10)
NE (Sites 2, 1, 4, 12, 6, 7)
Control (Sites 14, 15, 16)

TABLE 11

RELATIONSHIP BETWEEN SOIL CHEMICAL AND FERTILITY PARAMETERS
AND BARLEY YIELD AT ALL NANTICOKE SPRING GRAIN STUDY SITES - 1985

Parameter Tested	Correlation Coefficient	Statistical Significance (probability)
<u>Soil Fertility Parameters</u>		
available phosphorus	0.496	n.s.
available potassium	0.314	n.s.
available magnesium	N/C*	n.s.
available zinc	0.512	s ($p \geq 95\%$)
available manganese	-0.010	n.s.
pH	0.184	n.s.
<u>Soil Chemical Parameters</u>		
nitrogen	0.361	n.s.
C.E.C.	-0.006	n.s.
sulphate	-0.404	n.s.
available aluminum	-0.186	n.s.
available potassium	0.127	s ($p \geq 95\%$)
available magnesium	-0.543	n.s.
available calcium	0.069	n.s.
pH (water)	-0.050	n.s.
pH (CaCl_2)	0.043	n.s.
total zinc	0.386	n.s.
total vanadium	0.151	n.s.
total selenium	0.472	n.s.
total antimony	-0.170	n.s.
total lead	0.228	n.s.
total nickel	-0.187	n.s.
total molybdenum	N/C	n.s.
total mercury	0.717	s ($p \geq 99\%$)
total iron	-0.051	n.s.
total copper	0.387	n.s.
total chromium	-0.074	n.s.
total cadmium	0.208	n.s.
total arsenic	-0.194	n.s.
total aluminum	-0.221	n.s.

* N/C - not calculated as all values the same

** n.s. not significant

s. significant (probability $\geq 95\%$ or 99%)

TABLE 12

SUMMARY OF BARLEY ANALYSES RESULTS FOR SAMPLES COLLECTED IN THE MANTICOCK SPRING BRAIN STUDY AREA
- JULY 10-11, 1985

Location		Sector	Chemical Concentration of Barley Foliar (ppm dry wt. basis)																				
			U	Fe	Mn	Al	As	B	Cl	Co	Cr	Cu	F	Hg	Mg	Ni	Pb	Sb	Se	S	Ti	V	Zn
Site 5 Site 3 Site 11 Site 9 Site 8 Site 10	N	<0.05	260	38	200	0.25	18	4000	1	4	7	<1	0.02	0.8	<1	2	<0.05	<0.05	5800	14	<1	14	
	O	<0.05	470	74	510	0.07	15	10100	1	5	6	8.8	0.05	0.7	1	2	<0.05	<0.05	4200	34	1	12	
	R	<0.05	460	22	450	0.16	14	7100	1	2	5	5.6	0.05	1.4	<1	2	<0.05	0.16	5400	51	1	6	
	T	<0.05	150	47	110	<0.05	15	18100	<1	2	6	5.6	0.04	1.4	<1	1	<0.05	0.16	5100	11	<1	40	
	H	<0.05	250	57	250	0.16	14	17600	1	2	6	4.1	0.05	1.7	<1	2	<0.05	<0.05	5200	17	<1	19	
	10	<0.05	190	26	170	<0.05	15	4100	<1	2	6	2.7	0.04	1.0	<1	2	<0.05	0.16	4700	24	<1	10	
Site 2 Site 4 Site 1 Site 12 Site 6 Site 7	N	<0.05	870	42	1000	<0.05	16	9600	2	5	6	6.4	0.05	0.8	2	4	<0.05	0.16	3100	65	2	15	
	O	<0.05	320	37	320	0.07	15	1000	1	2	7	5.4	0.05	1.0	1	2	<0.05	0.25	5500	27	<1	10	
	R	<0.05	260	82	260	<0.05	15	15000	<1	2	5	5	0.05	0.7	<1	2	<0.05	<0.05	4000	25	<1	14	
	T	<0.05	260	42	250	0.16	14	5800	<1	2	6	2.4	0.05	0.7	<1	<1	<0.05	0.16	4500	20	<1	9	
	H	<0.05	340	45	390	<0.05	14	9100	<1	5	4	2.8	0.05	0.8	<1	2	<0.05	<0.05	4700	56	<1	26	
	7	<0.05	240	47	210	<0.05	12	4900	<1	2	4	2.5	0.05	0.6	<1	<1	<0.05	<0.05	4100	22	<1	7	
Site 14 Site 15 Site 16	C	<0.05	280	88	350	0.07	11	3100	<1	5	7	1.8	0.04	0.5	<1	1	<0.05	<0.05	5200	21	<1	17	
	O	<0.05	160	40	130	0.16	11	8700	<1	1	4	1.6	0.05	0.8	<1	1	<0.05	<0.05	6500	16	<1	10	
	N	<0.05	140	75	120	0.07	15	7600	<1	2	5	6.5	0.05	0.7	<1	2	<0.05	0.16	5500	15	<1	7	
	16																						
Phytotoxicology Upper Limit of Normal (Grasses)			-	500	50	-	-	20	0.5	2	5	7	12	-	6	5	20	-	0.5	5000	-	6	40
Upper Critical Level for Spring Barley*			-	-	-	-	20	0.0	1%	6	10	20	-	5	1%	26	55	-	50	-	-	2	790

* from Davis et al., 1978

TABLE 13

RELATIONSHIP BETWEEN BARLEY FOLIAR CHEMISTRY AND CROP YIELD
AT ALL NANTICOKE SPRING GRAIN STUDY SITES - 1985

Parameter Tested	Correlation Coefficient	Statistical* Significance (probability)
<u>OMAF Tissue Nutrient Analysis</u>		
nitrogen	0.622	s. (p≥95%)
phosphorus	0.656	s. (p≥99%)
potassium	-0.207	n.s.
magnesium	0.423	n.s.
boron	-0.390	n.s.
copper	0.087	n.s.
iron	-0.064	n.s.
manganese	-0.477	n.s.
zinc	0.419	n.s.
<u>MOE Foliar Chemistry</u>		
uranium	N/C**	n.s.
iron	-0.296	n.s.
manganese	-0.479	n.s.
aluminum	-0.348	n.s.
arsenic	-0.092	n.s.
boron	-0.018	n.s.
cadmium	-0.188	n.s.
chloride	0.028	n.s.
cobalt	-0.102	n.s.
chromium	-0.468	n.s.
copper	0.102	n.s.
fluoride	-0.186	n.s.
mercury	0.335	n.s.
molybdenum	0.270	n.s.
nickel	-0.102	n.s.
lead	-0.136	n.s.
antimony	N/C	n.s.
selenium	0.348	n.s.
sulphur	0.093	n.s.
titanium	0.241	n.s.
vandium	-0.102	n.s.
zinc	-0.085	n.s.

* n.s. not significant
s. significant (probability ≥95% or 99%)

** N/C - not calculated as all results the same

TABLE 14

COMPARISON OF SOIL PHYSICAL PROPERTIES AT ALL NANTICOKE SPRING GRAIN STUDY SITES - 1985

Location	Direction	Soil Physical Properties					
		Average Depth to Hard- Pan (cm)	Bulk Density of Hard- Pan	Root Penetration* of Hard-Pan	Particle Size Sand	Particle Size Silt	Organic Carbon Clay (%)
Site 5	N	5-8	1.6	3	19	46	35
Site 3		5-8	1.7	2	12	31	57
Site 11		10-13	1.7	3	13	47	39
Site 9		>15	1.5	7	9	39	52
Site 8		13-15	1.5	4	12	39	49
Site 10		10-13	1.7	3	26	43	30
Site 2	NE	4-5	1.8	3	15	43	41
Site 4		13-15	1.6	3	13	38	49
Site 1		>15	1.7	3	14	45	41
Site 12		8-10	1.7	4	9	44	46
Site 6		4-5	1.7	1	10	41	48
Site 7		4-5	1.6	2	10	39	51
Site 14	CONTROL	4-5	1.6	2	10	44	46
Site 15		>15	1.9	3	19	49	31
Site 16		>15	1.7	3	11	45	44
							1.80
							2.30
							2.90

* Root Penetration: Scale of 0-10 where 0 = no root penetration; 10 = excellent root penetration

TABLE 15

SUMMARY OF BARLEY PHYSICAL CHARACTERISTICS AND HAND HARVESTED
BARLEY YIELD FOR ALL SITES IN THE NANTICOKE SPRING GRAIN STUDY AREA - 1985

Location	General Direction	Barley Crop Characteristics					Grain Yield (bu/ac)
		Ave.* Plant Height (cm)	Ave.* Number of Tillers per Plant	Ave.* Head Length (cm)	Ave.* Head Weight (g)	Ave.* Root Fresh Weight (g)	
Site 5	N	56	2.2	8.6	3.0	1.05	71.6
Site 3		75	1.8	6.1	3.5	0.95	71.5
Site 11		57	2.6	5.5	5.4	1.75	67.1
Site 9		87	1.9	7.1	4.2	1.37	93.7
Site 8		93	2.2	7.4	3.9	2.49	73.5
Site 10		79	2.1	7.8	7.0	2.93	102.1
Site 2	NE	78	1.5	5.6	3.1	1.09	71.6
Site 4		86	2.4	8.3	7.3	1.97	92.5
Site 1		67	2.6	7.3	3.9	1.48	81.5
Site 12		75	1.7	7.0	4.7	1.36	80.5
Site 6		55	1.6	6.1	3.8	1.21	64.1
Site 7		72	1.7	7.0	4.5	1.17	78.3
Site 14	CONTROL	55	1.4	5.9	2.8	0.86	47.1
Site 15		75	2.2	6.0	4.9	2.19	96.2
Site 16		69	1.5	5.1	2.2	0.37	64.2

* Average values calculated from individual plant measurements from 6 different locations in each field
(number of plants measured varied from 19-47 among the 15 fields)

TABLE 16

RELATIONSHIP BETWEEN CROP AND SOIL PHYSICAL PARAMETERS
AND BARLEY YIELD AT ALL NANTICOKE SPRING GRAIN STUDY SITES - 1985

Parameter Tested	Correlation Coefficient	Statistical Significance (probability)
<u>Soil Physical Parameters</u>		
Depth to Hard-Pan	-0.537	s. ($p \geq 95\%$)
Bulk Density of Hard-Pan	0.118	n.s.
Root Penetration	0.465	n.s.
Soil Particle Size % Sand	0.502	s. ($p \geq 95\%$)
% Silt	-0.029	n.s.
% Clay	-0.298	n.s.
Organic Carbon	0.263	n.s.
<u>Crop Physical Parameters</u>		
No. Tillers	0.462	n.s.
Plant Height	0.632	s. ($p \geq 95\%$)
Head Length	0.511	s. ($p \geq 95\%$)
Root Weight	0.670	s. ($p \geq 99\%$)
Head Weight	0.716	s. ($p \geq 99\%$)

TABLE 17

40

DESCRIPTION OF BARLEY SITES - FIELD HISTORY

Location	Field Location in relation to Nanticoke Industrial Complex	Lot	Location Con.	Twp.	Soil Type	Tiled (Y/N)	Previous Crops Grown 1984	1983	1982
Site 1	NE	22	2	Walpole	Hald. Clay	N	Soybeans	Soybeans	Soybeans
Site 2	NE	14	1	Walpole	Clay Loam	N	Corn	Corn	Red Clover
Site 3	N (Texaco Farm)	11	2	Walpole	Clay Loam	N	Corn	Corn	Red Clover
Site 4		19	3	Walpole	Hald. Clay	N	Fallow	Fallow	Corn
Site 5		7	2	Walpole	Hald. Clay	N	Corn	Corn	Corn
Site 6	NE	5	6	Rainham	Hald. Clay	N	Corn	Soybeans	Red Clover
Site 7	NE	10	6	Rainham	Hald. Clay	N	Soybeans	Wheat	Hay
Site 8	N	24	9	Walpole	Hald. Clay	N	Wheat	Corn	Corn
Site 9	N	19	9	Walpole	Hald. Clay	N	Soybeans	Barley	Corn
Site 10	N	19	12	Walpole	Clay Loam	N	Corn	Corn	Corn
Site 11	N	14	6	Walpole	Hald. Clay	N	Soybeans	Corn	Corn
Site 12	NE	3	4	Rainham	Hald. Clay	N	Hay	Hay	Hay
Site 14	ENE	20	5	S. Cayuga	Hald. Clay	N	Corn	Red Clover	Wheat
Site 15	ENE	5	4	Dunn	Hald. Clay	N	Soybeans	Soybeans	Soybeans
Site 16	ENE	17	4	Dunn	Clay Loam	N	Soybeans	Soybeans	Soybeans

TABLE 18

DESCRIPTION OF BARLEY STUDY SITES
- TILLAGE OPERATIONS

Field#	Primary Tillage		Secondary Tillage	
	Tool	Depth	Tool	Depth
1	Fall cultivator	3"	Cultivator & harogator (3x)	2½"
2	Fall plowed	6"	Cultivator	6"
3	Fall plowed	6"	Cultivator	6"
4	Fall plowed	6"	Cultivator (3x)	2-3"
5	Fall plowed	4-6"	Cultivator (2x)	3"
6	Fall plowed	6"	Danish Cultivator	3"
7	Fall plowed	7"	Cultivator & harrow (3x)	3"
8	Fall plowed	6"	Cultivator (2x) disc harrow after planting	3"
9	None	-	None	-
10	Fall plowed	8"	Disc (1x) Cultivator (2x)	2-3"
11	Fall plowed	6"	Disc (1x), Springtooth and harrow (1x)	3"
12	Fall plowed	5"-7"	Disc (2x), harogator	3"
13	Fall plowed	6"	Cultivator & harogator (2x)	3"
14	Soil saver	6-8"	Cultivator, Cultivator & harrow	2½-3"
15	Fall plowed	4-5"	Disc	3-3½"

TABLE 19

DESCRIPTION OF BARLEY STUDY SITES -
PLANTING AND HERBICIDE DATA

Field#	Planting Data			Herbicide Program			
	Variety	Seeding Rate (bu/ac)	Date	Under- seeded	Crop Ins.	Product	Rate
1	Rodeo	2½	April 25	N	Y	none	-
2	Perth	2	April	Y	Y	none	-
3	Perth	2	April	Y	Y	none	-
4	Leger	2½	April 25	N	Y	MCPA	½L/ac
5	Birka	2	April 19	Y	N	2,4-DB	-
6	Leger	2½	May 7	Y	Y	2,4-DB	-
7	Leger	2	April 23	Y	N	2,4-DB	-
8	Rodeo	2	April 23	N	N	none	-
9	Leger (broadcast)	2	April 12	N	N	MCPA	½L/ac
10	Leger	2	April 17	N	N	MCPA	½L/ac
11	Bruce	2	April 24	N	N	MCPA	½L/ac
12	Leger	3	April 27	N	N	2,4-D	½L/ac
14	Leger	2½	April 23	N	Y	2,4-D	½L/ac
15	Leger	2	April 25	Y	Y	Tropotox	½L/ac
16	Bruce	1 3/4	May 6	N	Y	none	-

TABLE 20

SUMMARY OF OMAF - SOIL TEST RESULTS - 1985

Field No.	Soil Test Values							Recommended Nutrients		
	P ₂ O ₅	K ₂ O	pH	Mg	Mn	Zn	%OM	Limestone t/ha	Phosphorous kg/ha	Potash kg/ha
1	22H	173H	5.5	200+	16	14	4.6	5	0	0
2	17H	193VH	6.0	200+	19	17	3.6	2	20	0
3	12M	155H	5.8	200+	16	14	3.7	3	50	0
4	14M	179H	6.7	200+	28	25	4.1	0	20	0
5	17M	141M	6.3	200+	37	24	3.8	0	20	20
6	11M	158H	6.4	200+	37	28	3.6	0	50	0
7	11M	211VH	6.1	200+	23	26	3.9	0	50	0
8	44VH	283E	6.7	200+	15	23	3.8	0	0	0
9	34VH	285E	6.0	200+	31	42	3.5	3	0	0
10	36VH	151H	6.3	200+	29	42	4.3	0	0	0
11	17M	162H	6.2	200+	19	15	4.2	0	20	0
12	9L	128M	5.4	200+	19	14	3.8	5	70	20
14	9L	97M	5.3	200+	30	22	3.9	6	70	30
15	23H	145M	5.4	200+	28	25	4.2	5	0	20
16	16M	157H	5.7	200+	30	22	4.1	9	20	0

E = excessive
 VH = very
 H = high
 M = medium
 L = low

TABLE 21

SUMMARY OF OMAF - PLANT TISSUE ANALYSIS RESULTS - 1985

Field No.	Nutrient									
	N %	P %	K %	Ca %	Mg %	Zn ppm	Fe ppm	Mn ppm	B ppm	Cu ppm
1	3.95	0.39	2.14	0.9	0.18	23	165	44	8	9
2	3.87	0.45	2.13	0.85	0.24	21	155	38	11	7
3	3.90	0.42	2.19	0.9	0.22	24	130	47	2*	8
4	3.82	0.44	1.80	0.76	0.26	28	93	26	4	8
5	3.84	0.34	1.74	0.89	0.19	25	133	31	11	10
6	3.06	0.42	2.07	0.47	0.15*	21	100	31	11	8
7	3.28	0.40	2.06	0.62	0.18	27	84	27	8	1*
8	3.82	0.39	2.82	1.24	0.23	30	78	34	9	8
9	4.78	0.50	1.94	0.78	0.19	33	98	18	7	9
10	4.53	0.48	1.92	0.86	0.23	33	103	28	1*	10
11	3.17	0.37	1.96	1.05	0.14*	22	88	19	1*	9
12	4.39	0.39	1.43	0.74	0.21	29	70	48	1*	9
14	3.98	0.38	1.98	0.73	0.22	28	89	66	10	8
15	3.59	0.36	2.22	0.69	0.20	36	102	47	13	9
16	3.40	0.49	2.35	0.49	0.11*	27	78	17	3	7

* denotes level below critical level

TABLE 22

HALDIMAND CO. RAINFALL RECORDS (INCHES)
(1975 - 1985)

<u>YEAR</u>	<u>MONTH</u>					Total
	April	May	June	July	August	
1975	0.8	1.75	3.25	2.4	6.55	14.75
1976	2.6	3.5	3.00	3.35	1.80	14.25
1977	3.3	2.1	3.55	3.3	4.95	17.20
1978	1.7	2.55	1.3	1.9	3.20	10.65
1979	2.61	2.57	2.2	1.93	4.47	13.78
1980	3.5	1.67	3.92	3.36	2.29	14.74
1981	3.18	2.37	3.75	3.41	2.67	15.38
1982	1.7	2.25	4.29	1.81	2.84	12.89
1983	3.37	4.00	3.05	5.59	3.51	19.52
1984	2.58	3.82	5.36	1.91	4.73	18.40
1985	0.78	2.83	2.78	2.27	4.65	13.31
Average (11 yr)	2.37	2.67	3.31	2.84	3.79	14.98
Range (H-L)	2.72	2.93	4.06	3.78	4.60	8.87

FIG 1

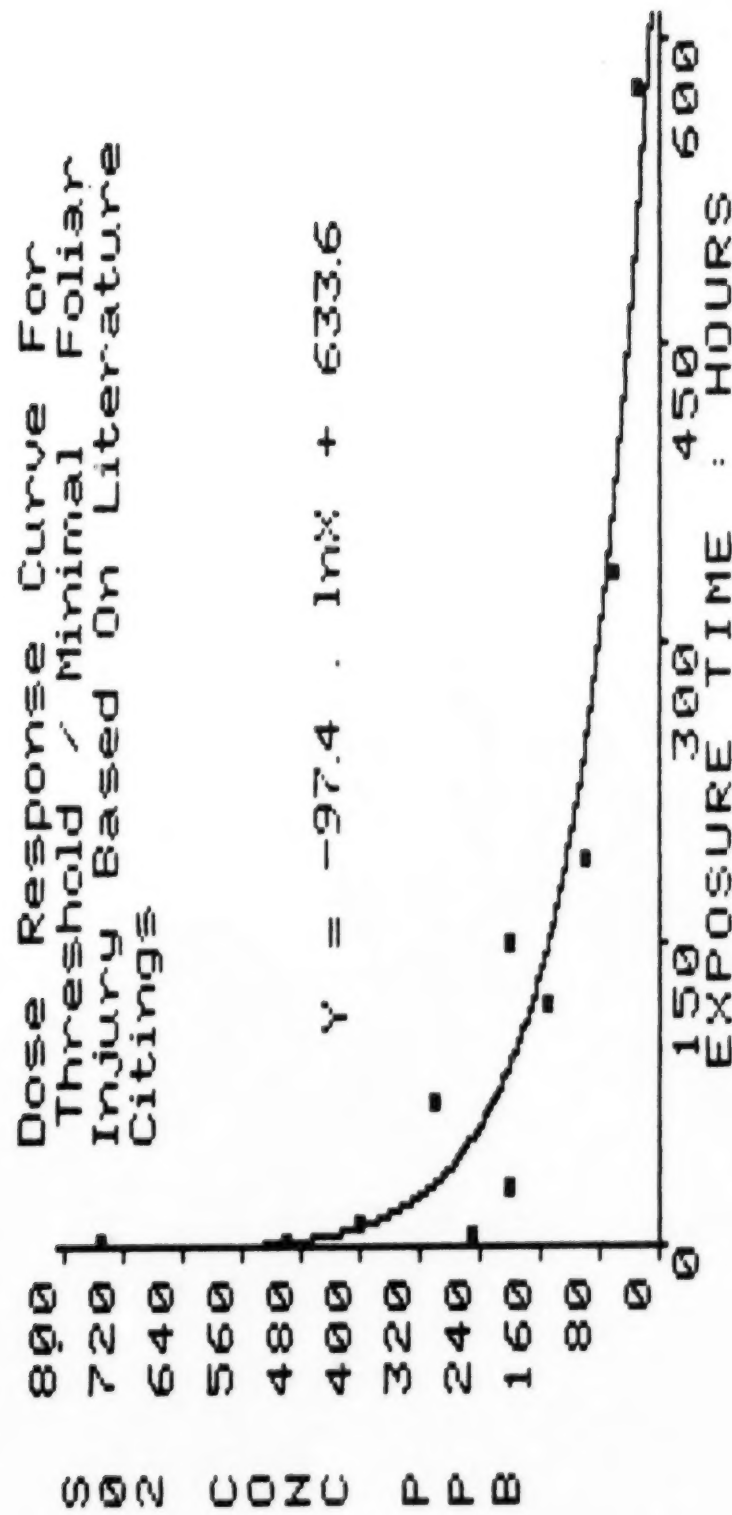


FIG 2

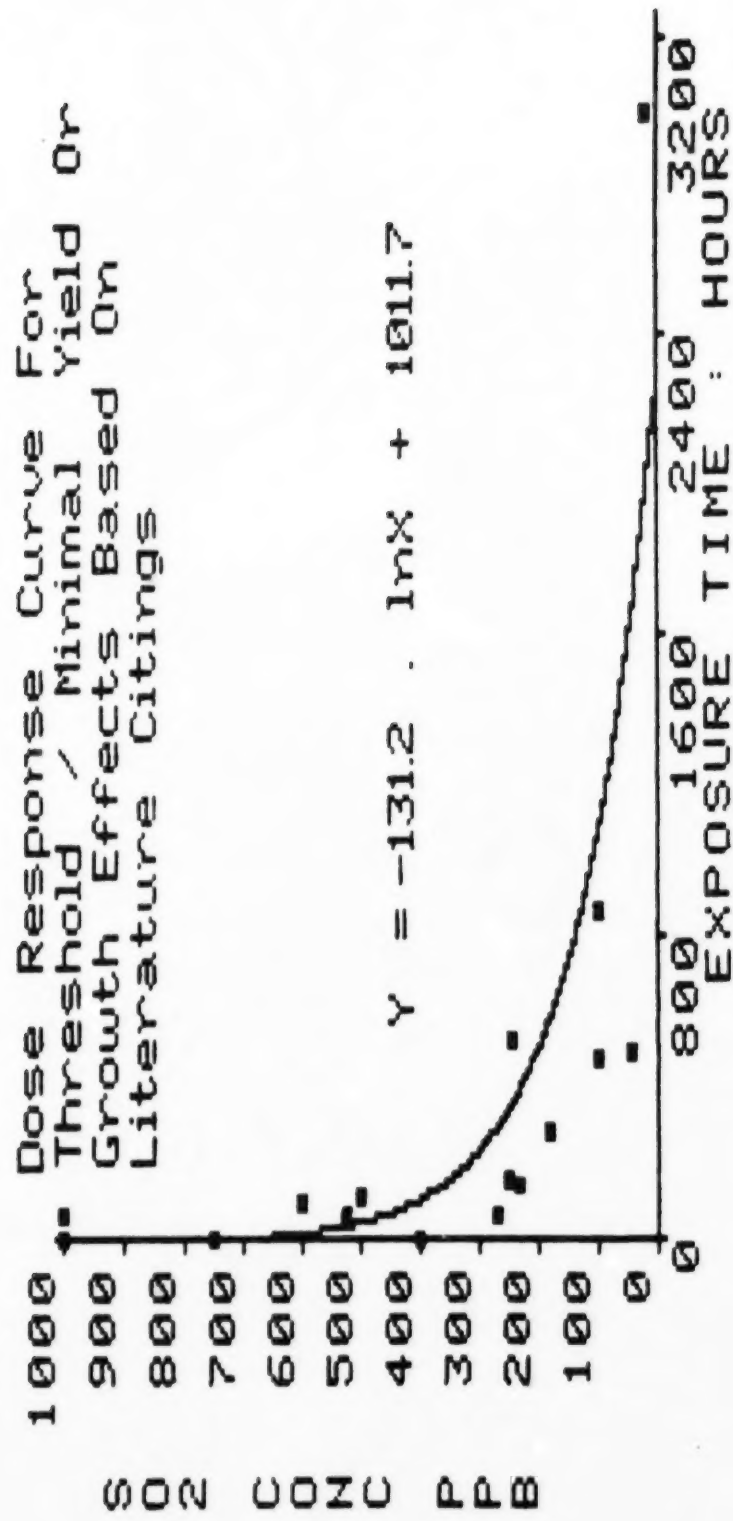


FIG 3

LOCATION OF AIR MONITORS IN THE NANTICOKE AREA : 1975-1985

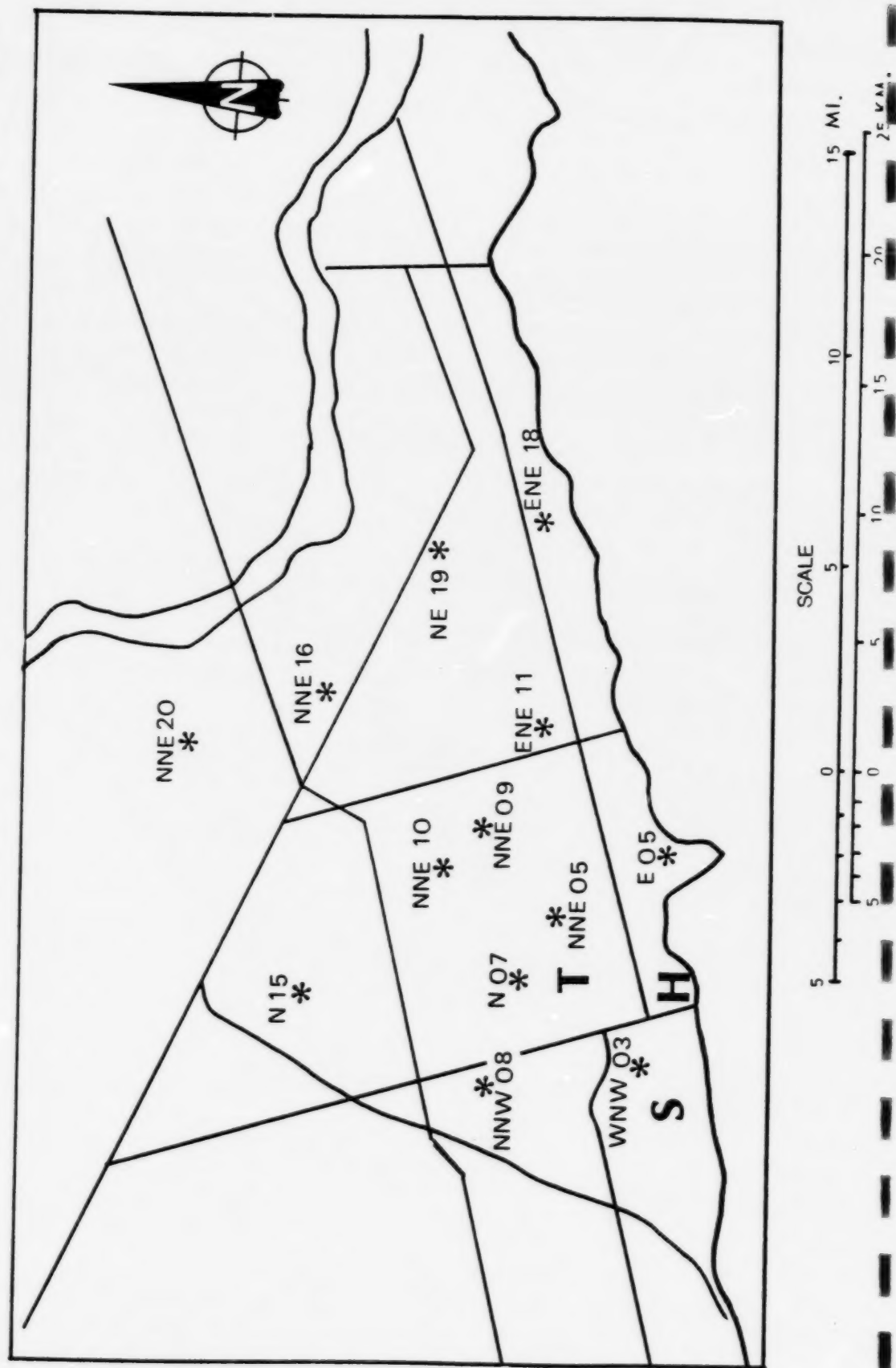


FIG 4

LOCATION OF BARLEY STUDY SITES IN THE NANTICOKE AREA - 1985

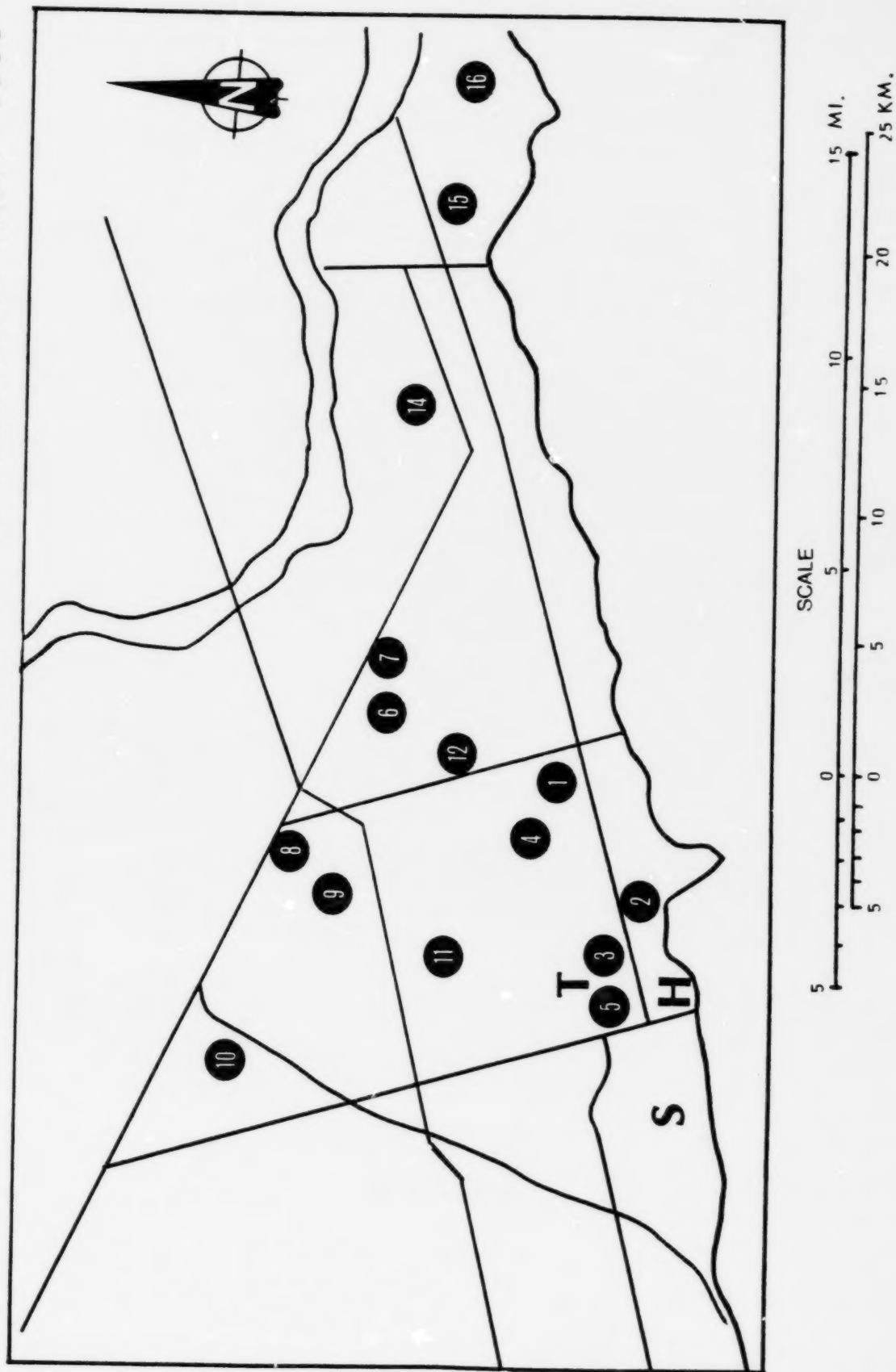


FIG 5

Regression of Historical Barley Yield on Rain
Apr.-Jun.
1975-85

